# InGaAs/AlGaAs QUANTUM WELL DBR LASER USING CURVED GRATING IN SELECTIVELY DISORDERED REGION

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## I. Introduction

Distributed Bragg reflector (DBR) lasers are attractive as light sources for monolithic photonic integrated circuits such as the master oscillator power amplifier[1]. One of the important requirements for implementing high performance DBR lasers is to reduce the absorption loss in the DBR region. Techniques to form low loss waveguides, such as selective-area epitaxy, selective-etching followed by regrowth and selective quantum well (QW) disordering, are used for this purpose. Disordering of QWs permits postgrowth widening of the effective band gap. By disordering the QW only within the area for the DBR, the passive waveguide loss in the DBR region at the lasing wavelength can be reduced significantly. The area-selective QW disordering method allows a simple and low-cost process compared to the others. Impurity-free vacancy diffusion by dielectric film deposition and rapid thermal annealing (RTA) is an effective way for disordering[2]. It allows loss reduction larger than that by impurity-induced disordering and the process can be performed simply using facilities for a conventional film deposition and RTA. DBR laser fabrication using selective disordering with $SrF_2$ and $SiO_2$ caps was reported[3]. We have reported selective disordering technique for InGaAs/AlGaAs strained single QW structure using $SiO_2$ caps of different thicknesses and demonstrated substantial loss reduction of passive waveguides[4]. In this paper, we demonstrate an InGaAs/AlGaAs QW DBR laser using a curved grating in a selectively disordered region, and present significant improvements of the laser characteristics.

## II. Selective QW disordering using $SiO_2$ caps of different thicknesses

Deposition of a $SiO_2$ cap layer on a QW structure followed by RTA induces absorption of the Ga atoms into the cap layer and generates vacancies in the III-V semiconductor crystal[2]. The vacancies diffuse toward the QW and promote interdiffusion between the atoms in the QW and barriers. As a result, the effective band gap of the QW is widened. If the cap does not absorb significantly Ga atoms, few vacancies are generated and disordering would be suppressed. A very thin $SiO_2$ cap is expected to work as such a suppression cap because of saturation of Ga absorption.

In this work, an InGaAs/AlGaAs strained single QW graded-index separate-confinement heterostructure was used[5]. To evaluate effective bandgap difference between the suppressed and disordered areas, we formed the disordered and suppressed areas in one substrate, and Fabry-Perot (FP) lasers were fabricated in both areas. $SiO_2$ caps of 300 nm and 30 nm thickness were deposited by PCVD for the disordering and suppressing caps, respectively, and RTA was performed at 900ºC, 920ºC and 940ºC for 15 s. Then, electrode formation and cleaving were performed. The lasing wavelengths were measured and the results are shown in Fig. 1. For the RTA temperature of 920ºC, a large difference in the wavelength of 23 nm was obtained. To evaluate the loss reduction in the passive waveguide, a FP laser integrated with disordered passive waveguides was fabricated. Using the measured output power dependence on the injection current, the external differential quantum efficiency was determined. From the efficiency, the passive waveguide loss for the disordered waveguide was calculated as 3 $cm^{-1}$ while the loss for an undisordered waveguide determined by the same method was roughly 40 $cm^{-1}$.

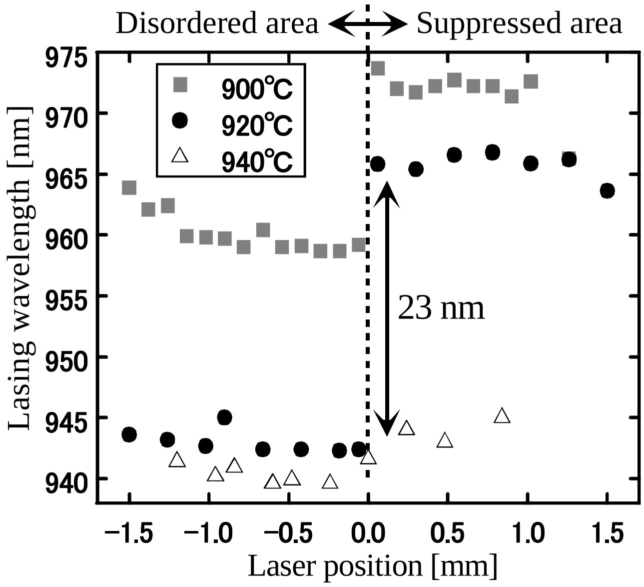


Fig. 1 Measured lasing wavelength of FP lasers fabricated in disordered and suppressed areas.

## III. Description and design

A schematic of the fabricated DBR laser is shown in Fig. 2. A surface grating was utilized for a simple fabrication process without regrowth, and a curved-DBR was adopted to feedback effectively the diverging guided wave from narrow channel [6]. The narrow ridge active channel with a width of 2 μm and a length of 600 μm is in the suppressed area and the DBR grating of 75 μm length is in the disordered area for passive waveguide loss

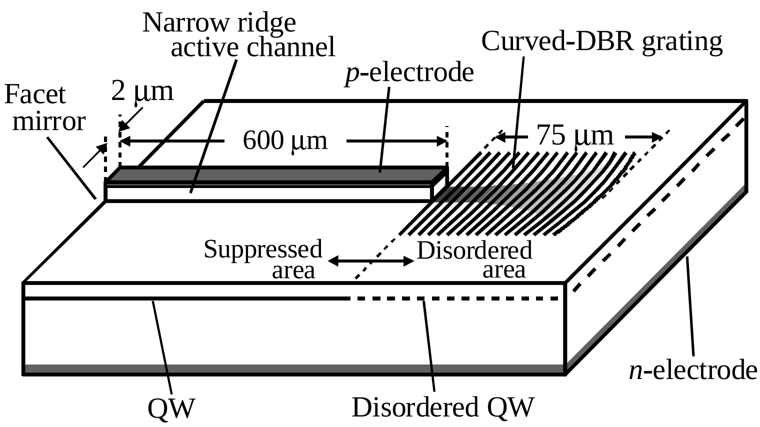


Fig. 2 Configuration of DBR laser using curved grating in selectively disordered region.

reduction. The design wavelength is 975 nm and the grating period is 446 nm (third order). The grating depth was determined as 150 nm. Theoretical values of the coupling coefficient and the radiation loss by first order diffraction were 140 $cm^{-1}$ and 9 $cm^{-1}$, respectively. Using these values, the reflectivities of DBRs with 3 $cm^{-1}$ and 40 $cm^{-1}$ losses were estimated as 60% and 50%, respectively.

## IV. Fabrication

After deposition of 300-nm and 30-nm thick $SiO_2$ caps for disordering and suppressing, respectively, RTA was performed at 920℃ for 15 s. In the suppressed area, a *p*-electrode for the active channel was deposited and a ridge structure was formed by reactive ion etching (RIE) using the electrode as a mask. In the disordered area, a curved-DBR grating was fabricated by electron beam writing and RIE. The wafer was thinned to 100 μm and an *n*-electrode was formed on the backside. Finally, the sample was cleaved. FP lasers with the same ridge structure and several different lengths were also fabricated.

## V. Experimental results

The dependences of the output power and the lasing wavelength from the cleaved facet on the injection current were measured under CW operation at room temperature. The results are shown in Fig. 3. The threshold current was 3.5 mA and the maximum output power of 60 mW was obtained at an injection current of 105 mA. Single-mode lasing over a range from threshold at a wavelength of 972.9 nm up to 60 mW output power at 974.4 nm was observed. The inset of Fig. 3 shows the lasing spectrum at an injection current of 30 mA. The side mode suppression ratio (SMSR) of 40 dB was obtained.

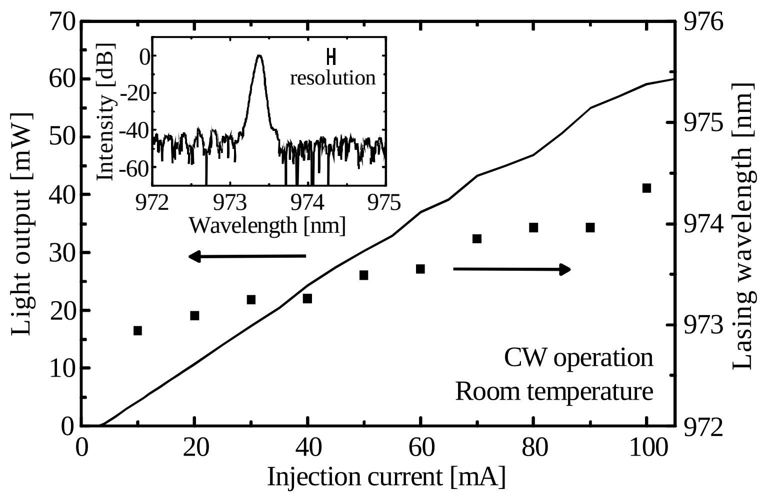


Fig. 3 Dependence of output power and lasing wavelength on injection current. Inset: Measured spectrum at $I$ = 30 mA

For the reference FP lasers, the external differential quantum efficiency dependent on the cavity length was measured. Then internal loss, $\alpha_i$, and the internal differential quantum efficiency, $\eta_i$, for the narrow ridge active channel structure were determined as 3 $cm^{-1}$ and 0.8, respectively. The measured external differential quantum efficiency, $\eta_d$, of the fabricated DBR laser was 0.51 ( 0.65 W/A ). The relation between the DBR reflectivity, $R_{DBR}$, and $\eta_d$ is described as

$$\eta_{\mathrm{d}} = \frac{\frac{1}{2L}\ln\left(\frac{1}{R_{\mathrm{DBR}}R}\right)}{\alpha_{\mathrm{i}} + \frac{1}{2L}\ln\left(\frac{1}{R_{\mathrm{DBR}}R}\right)} \cdot \frac{1}{1+\sqrt{\frac{R}{R_{\mathrm{DBR}}}} \cdot \frac{1-R_{\mathrm{DBR}}}{1-R}} \cdot \eta_{\mathrm{i}}\,, \qquad (1)$$

where $L$ is the cavity (channel) length and $R$ is the reflectivity of the facet mirror. By solving eq. (1), $R_{\mathrm{DBR}}$ was estimated as 70 %.

Table I shows the comparison between the present disordered DBR laser and the DBR laser we previously fabricated without disordering. The DBR reflectivity was largely improved. The experimental reflectivity for the disordered DBR is comparable with the theoretical value of 60%. For the undisordered DBR, the measured reflectivity is much smaller than the calculated value of 50%. The discrepancy suggests that the loss for the undisordered DBR laser is even larger than 40 $\mathrm{cm}^{-1}$. This is likely since the DBR laser lased at the Bragg wavelength of 973 nm, which is shorter than the lasing wavelength of 980 nm for the FP laser used to determine the loss. Table I also shows that the threshold current was 50% of the previous result, the maximum output power was doubled, and the SMSR was much better. The significant loss reduction in the DBR area contributed to expansion of the effective DBR interaction length. As a result, the reflectivity was enhanced and the SMSR was improved through enhancement of wavelength selectivity.

Table I Comparison between disordered and undisordered DBR lasers.

| | Disordered DBR laser | Undisordered DBR laser |
|---|---|---|
| DBR reflectivity | 70% | 20% |
| Threshold current | 3.5 mA | 7.1 mA |
| Maximum output power | 60 mW at 105 mA | 30 mW at 120 mA |
| Side mode suppression ratio | 40 dB | 20 dB |

## VI. Conclusion

We demonstrated the InGaAs/AlGaAs quantum well DBR laser using the curved grating in the selectively disordered region. Compared to the undisordered DBR laser, significant increase of DBR reflectivity, reduction of the threshold current, increase of maximum output power and improvement of SMSR were achieved.

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